MASTER COPY KEEP THIS COPY FOR REPRODUCTION PURPOSES

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE

3. REPORT TYPE AND DATES COVERED
6/94-5/98

4. TITLE AND SUBTITLE
Dopant Diffusion in InP and InGaAs

5. FUNDING NUMBERS
DAAH 04-94-G-0231

6. AUTHOR(S)
R.M. Cohen

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Department of Materials Science & Engineering
University of Utah
122 South Central Campus Dr. Room 304
Salt Lake City, UT 84112-0560 USA

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Office
P. O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
ARO 32532.6-MS

11. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
Record high hole concentrations using C-doping in InGaAs lattice matched to InP were achieved via atmospheric pressure organometallic vapor phase epitaxy. When annealing in the presence of atomic hydrogen, it was demonstrated for the first time that no hole passivation occurs unless a large quantity of broken bonds exist in the crystal. A combination of dopant solubility studies and diffusion studies in InP and InGaAs have been used to determine that the Fermi energy is pinned approximately 0.35eV below midgap during growth of InP, and is essentially unpinned during the growth of InGaAs lattice matched to InP.

14. SUBJECT TERMS
InP, InGaAs, diffusion, passivation, Fermi, energy pinning

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

FINAL REPORT

Statement of Problem: To study and to understand the diffusion and incorporation of dopants in InP and InGaAs. This work addresses key problems appearing in practical applications including (1) the substantial carrier passivation which occurs in heavily p-type material when atomic hydrogen is present, and (2) the difficulty in predicting the dopant concentration profiles incorporated during growth as a function of the ambient parameters, and their widely irreproducible variations in the rates of impurity diffusion during high temperature processing.

Key results:
(1-a) Carrier passivation. We have demonstrated that the passivation of holes by atomic hydrogen in InGaAs only occurs when the crystal has been damaged. When a high density of dangling bonds were created, we showed that hydrogen readily donated an electron and reduced the hole concentration by more than an order of magnitude. Passivation was fully reversible, i.e., high hole concentrations were recoverable when annealing in a hydrogen-free ambient. However, without dangling bonds present, no passivation of high hole concentrations occurred in ambients rich in atomic hydrogen.
(1-b) High hole concentration. Record high hole concentrations of 9×10^{19} cm^{-3} from C-doping in $In_{0.53}Ga_{0.47}As$ were achieved via atmospheric pressure organometallic vapor phase epitaxy.
(1-c) Heterojunction bipolar transistors (HBTs). One set of HBTs were fabricated with a simple 3 mask process, and DC betas of 2-20 were measured. These demonstrated that a C-doped base is practical. In contrast, similar structures grown with Zn in the base exhibited no transistor action. SIMS showed that Zn diffusion increased greatly during the growth of the n-type emitter layer, and no solution was found to reduce the Zn diffusion out of the base.
(2) Prediction and control of dopant concentration profiles. SIMS studies at ARL provided data which allowed us to show that the Fermi energy is pinned on the InP surface at typical processing temperatures, and to determine that it was pinned approximately 350 meV below the intrinsic Fermi energy. Similar studies showed that there was essentially no pinning at an $In_{0.53}Ga_{0.47}As$ surface. Insufficient SIMS data was obtained from ARL to analyze the effect of processing variables on the diffusion rates of Zn, Te, C, or Fe out of substrates.

Publications acknowledging ARO support.
1. A. Tandon, R.M. Cohen, M. Ervin, and R. Lareau, "Zn solubility and Fermi energy pinning in InP and InGaAs: growth vs equilibrium", submitted to Materials Science and Engineering B.
2. R.M. Cohen, "Diffusion via native defects, and the appropriate choice of independent thermodynamic variables in both quasi-equilibrium and nonequilibrium experimental designs", in Phase Transformations and Systems Driven Far From Equilibrium, E. Ma, P. Bellon, M. Atzmon, R. Trivedi, eds., Proc. MRS Fall 1997, vol. 481, in press.
3. A. Tandon and R.M. Cohen, "Very high hole concentrations in C-doped InGaAs using new sources with APOMVPE", Thin-Film Structures for Photovoltaics, E.D. Jones, R. Noufi, B.L. Sopori, J. Kalejs, eds., Proc. MRS Fall 1997, vol. 485, in press.
4. A. Tandon and R.M. Cohen, "Highly p-type carbon-doped InGaAs grown by atmospheric pressure organometallic vapor phase epitaxy", accepted in J. Crystal Growth, sched. 8/98, v. 192.
5. R.M. Cohen, "Diffusion and native defects in GaAs", Proc. of 1996 Conf. on Optoelectronic and Microelectronic Materials and Devices, Canberra, C. Jagadish, ed. (IEEE, Piscataway, 1997), pp. 107-113.
6. R.M. Cohen, "Point defects and diffusion in thin films of GaAs", Materials Science and Engineering **R20**, pp. 167-280 (1997).

Degrees awarded:

Ashish Tandon, PhD, 12/97. Employed as Member of Technical Staff at HP Labs, Palo Alto.